BEST STRATEGIES TO REDUCE INTERNAL ENERGY LOADS IN MULTI-UNIT RESIDENTIAL BUILDINGS

SBSP PROJECT COURSE

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EXECUTIVE SUMMARY

Multi-Unit Residential Buildings (MURBs) are considered to be the fastest growing building sector in British Columbia, now representing 31% of the BC Housing sector. Out of this, 63% are low-rise buildings and the rest (37%) are high-rise. In the city of Vancouver, MURBs now comprise 60% of the total residential sector; high utilization of glazed façade in the building envelope is considered to be a main feature of high-rise buildings in Vancouver. Another difference between conventional and modern MURBs is replacement of electrical baseboards by heat pumps for space heating.

MURBs to be constructed in province of British Columbia should comply with ASHRAE 90.1 (2004), whereas in the City of Vancouver, ASHRAE 90.1 (2007) has been set as the mandatory building code. However, switching to 2010 version of ASHRAE 90.1 is expected in the near future with the main purpose of more energy savings in coming years. In addition, The City of Vancouver aims to be Carbon-Neutral for all New Constructions by 2020[1], which is greatly tied to building energy use intensity. Inevitably, building envelope design and associated mechanical equipment should be reviewed carefully to be aligned with these goals and baselines. Currently in Vancouver, buildings are responsible for 55% of GreenHouse Gas (GHG) emissions due to their construction and operation.[2]

Achieving energy efficient buildings is much more cost-effective when integrated at early design stages compared to rehabilitation practices. This is more apparent when the long life-span of an average building is taken into account.

To further understand these effects, this study was conducted by UBC Sustainable Building Science Program and BC Hydro New Construction Program. Energy modeling results of a number of newly designed high-rise and mid-rise residential buildings within Lower Mainland, recently incentivized by BC Hydro NCP, were analysed. Twelve energy conservation measures (ECMs) have been installed in these buildings to perform better

[1] Green Buildings (2012). Retrieved from (City of Vancouver, 2012) http://vancouver.ca/green-vancouver/green-buildings.aspx
[2] Light house, intep, BTY Group (2012). Towards Carbon Neutral Buildings in BC, Framework for High-rise Multi-Unit residential Buildings

than the current code according to the methodology defined by BC hydro NCP. The main objective was set as exploring potential areas of more cost-effective ECMs with lower Carbon footprints in MURBs. Energy Use Intensity in buildings and end use areas were studied and a comprehensive economic analysis was performed to observe the main regions of attained energy savings.

Throughout the study, it was found that much of energy savings in space heating end use area were accomplished by engaging high efficiency heating, ventilation and air conditioning (HVAC) systems (heat pumps) without making an effort to design a more efficient enclosure. Specific to high-rise buildings, a comparison between current natural gas/electricity ratio and historical data reveals that first, the total consumption has not declined significantly and second, the share of electricity consumption has been raised, associated with decreased natural gas consumption.

To conserve energy beyond the code and reduce the GHG emissions significantly within residential building, it is recommended to:

- Reduce energy wastes from glazing by providing optimum exterior shades and window shutters, less glazing ratio, and improving the R-value of glazing;
- Move from all air systems to hydronic panels;
- Switch from conventional boilers to district energy systems, hot water heat pumps, or at least condensing boiler; and
- Enforce implementing more efficient elevators.

In terms of cost effective ECMs within their life expectancy, exterior lighting control, high efficiency glazing, variable speed driven pumps/fans, domestic hot water (DHW) preheating, DHW low flow fixtures and high efficiency HVAC systems deemed to be promising measures whereas measures related to wall/roof insulation showed prolonged payback periods.

More incentives seem necessary in lighting control end use areas due to the present long payback periods while also being required by the next code (ASHRAE 90.1 -2010).

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1. INTRODUCTION

A relatively new trend has been created recently in British Columbia, specifically in the Lower Mainland, where people opt to live in Multi-Unit Residential Buildings (MURBs) instead of conventional detached houses, which puts MURBs among the fastest growing building sectors in BC. There are multiple reasons behind this, including lifestyle, the desire for living near populated areas, spectacular views of the ocean and mountains, as well as suitable land shortage and climatic conditions. The types of ownership are private or public ownership, partial ownership, rentals or social housing. Most often, private ownership of residential suites and shared ownership of common areas such as stairs, recreation areas, corridors, elevators, and parking areas is preferred[3].

A very high proportion of visible glass is currently being used in Lower Mainland high-rise buildings. Comparatively low prices of energy carriers, mainly electricity and natural gas, in BC along with milder climate of BC compared to the rest of Canada are the major drivers of high glass proportions used in current high-rise buildings. MURBs are designed and constructed in accordance with the requirements of ASHRAE 90.1-2004 and ASHRAE 90.1-2007 energy codes. In the near future, ASHRAE 90.1-2010 energy code will be adopted, which demands undertaking further energy conservation practices for coming years. Furthermore, the City of Vancouver aims to be Carbon-Neutral for all New Constructions by 2020[4], which would not be achieved without improvements in building envelope design, and strict requirements for building mechanical systems.

Relative energy efficiency of new buildings will influence energy consumption for several years due to the long lifespan of most buildings. Compelling opportunities for energy efficiency exist in the design and construction stage of buildings, since modifications during a building's design phase require smaller costs with greater potential energy savings relative to later retrofits. For instance, decisions regarding the form of the building, its

[3] Finch, G., Burnett, E., & Knowles, W. (n.d.). Energy Consumption in Mid and High Rise Residential Buildings in British Columbia, *BEST2-Energy Efficiency –Session EE3-1*

[4] Green Buildings (2012). Retrieved from (City of Vancouver, 2012) http://vancouver.ca/green-vancouver/green-buildings.aspx

orientation, the orientation of its windows, and its structural materials will entail no or very low cost at the early project stage[5].

1.1. Objectives

The overall objective of this project is to critically review the current practices for energy conservation in Lower Mainland multi-unit residential buildings and determine the areas with potential for further improvement. Specific objectives are:

- To conduct a comprehensive literature review about building energy codes and current practices in BC Multi-Unit Residential Buildings (MURBs)
- To analyse energy modeling results of selected MURBs in Lower Mainland, funded by BC Hydro New Construction Program, to determine potential areas for further conservation
- To conduct a cost/benefit analysis on 12 Energy Conservation Measures currently used in newly designed MURBs in Lower Mainland
- To compare building energy codes in BC with Europe to identify possible areas of improvement
- To provide recommendations to go beyond the current code and move towards ASHRAE 90.1-2010

2. Literature Review

2.1. Background of Energy Consumption Within MURBs

In Canada, the building sector consumes approximately 30% of all secondary energy[6,7]. Of this 30%, residential buildings account for approximately 16% while commercial and institutional buildings use 14%. It is estimated that 18% of energy within the residential sector

[5] Laustsen, J. (2008), Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, IEA Information Paper, International Energy Agency
[6] Secondary energy is the energy used by consumers and does not account for energy production
[7] Comprehensive Energy Use Database Tables (2011). Retrieved from (Natural Resources Canada) http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_res_ca.cfm

is used in apartment buildings. Almost half of the natural gas and 35% of the electricity is consumed in residential buildings in the city of Vancouver. In 2011, it has been reported that 61% of the MURBs in BC have electric baseboard heaters[8].

2.2. Current Practice in MURBs

There are characteristics in Multi Unit Residential Buildings (MURBs) specific to Vancouver, when reviewing the construction history in this sector. The first is the relatively high glazing ratio which has given the title of "City of Glass" to Vancouver. Recent design practices also tend to use metal panel cladding, window walls/spandrel panels instead of punched windows and concrete fins within high rise buildings. The building envelope has the primary function of controlling the heat and moisture flow to provide comfort while reducing the associated waste of energy especially during predominant heating season in Vancouver.

Recently an exhaustive study[9] was completed by the RDH Engineering Company which investigated 39 MURBs located in Lower Mainland and Victoria (built before 2005) to assess the levels of energy consumption. The average size of the studied MURBs was 18 floors (range of 5 to 33 floors) and 113 units (range of 16 to 212 suites) with an average area of 11,023 m^2.

Typical mechanical systems included make up air units providing fresh and heated air to common areas (hallways and lobby) and electrical baseboard units within suites. The suites were also equipped with gas fireplaces for space heating. An exhaust fan in each unit service area was installed to exhaust the air to reduce humidity.

The study revealed that an average high-rise MURB consumed 213 kWh/m^2 annually, with the maximum and minimum values of 299 and 144 $kWh/m^2/yr$ respectively. Typically, 37% of this energy was spent for space heating and ventilation. On average, 69% of this amount of energy was provided by gas burning equipment. This is surprising as the majority of buildings

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[8] Pape-Salmon, A., Fisher, J., Knowles, W., & Sanguinetti, J. (2012). Multi-Unit Residential Buildings in BC, Innovation Feature, Retrieved from http://www.bchousing.org/resources/Media_Centre/In_the_News/MURBsBC.APEG.Sept.12.pdf

[9] RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia, *Final Report*

were equipped with electrical baseboards for space heating. The study has highlighted "the significant disconnect between building energy consumption and direct billing to occupants for their share of total energy usage, and the need for individual suite metering."[10]

The report noted that 49% of the total energy consumption within a typical building (213 kWh/m^2) was dedicated to electricity (equal to 102 kWh/m^2) and 51% was provided by natural gas (equal to 111 kWh/m^2).

To understand the current energy performance of a mid-rise building and be compatible with the data on high-rise buildings, statistics of NRCan 2005 were reviewed and the average energy intensity of a mid-rise building (<5 storeys) in British Columbia, was found to be 239 kWh/m^2 per year[11].

2.3. Building Energy Codes in MURBs: Now and Future

Building energy codes are used as guideline through a new design or rehabilitation process to achieve the minimum required efficiency as well as the lowest impact on the environment. In North America, new commercial and residential buildings (over three storeys) are regulated by ASHRAE 90.1, developed by the American Society of Heating, Refrigeration and Air-conditioning Engineers for different climate zones.

Compliance with the ASHRAE standard can be achieved in three different ways[12]:

1. Prescriptive approach

   Following the prescriptive path, prescribed requirements, set out in a series of tables, must be adopted for all individual building components in categories of building envelope, HVAC systems, service water heating, power, lightning and other equipment.
2. Envelope trade off method

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[10] RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia, *Final Report*

[11] Energy Use Data Handbook Tables (2005). Retrieved from (Natural Resources Canada) http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_res_ca.cfm?attr=0

[12] Laustsen, J. (2008). Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, IEA Information Paper, International Energy Agency

In this method, values are set for each building component but a trade-off can be made, provided that the final energy consumption is less than the first calculated assessment.

3. Energy cost budget (ECB) method

   By this approach, the recommended model should demonstrate that overall annual energy cost is less than the base case where all building components were set at minimum prescribed characteristics.

The current code for residential buildings in BC is ASHRAE 90.1- 2004 whilst the City of Vancouver Building Bylaw (VBBL) mandates ASHRAE 90.1-2007 for multi-unit residential buildings. There are differences between these two versions, in particular with respect to building enclosure and window requirements. Furthermore it is anticipated that the next version (AsSHRAE90.1-2010) will be adopted soon in Vancouver, so the necessary provisions are being made.

The main changes can be summarized in the following categories:

1. Exterior surfaces: the R-values of walls, roofs and exposed floor should be increased.
2. Glazing: the overall performance of windows should be improved by increasing the R-values as well as decreasing the glazing ratio from 50% to 40%
3. Interior lighting: the required lighting intensities should be reduced from 0.7 W/ft^2 to 0.58 W/ft^2 (not in suites) and occupancy sensors are also required in stairwells.
4. Exterior lighting: lighting intensities in building exterior should reduce from 10kW to 6.1 kW; occupancy sensors are also required in parking area.

ASHRAE 90.1-2010 was developed with the intention of achieving an average of 30% energy savings compared to ASHRAE 90.1-2004. Several studies have been done by different companies to verify this goal and predict the challenges and impacts of these substitutions.

Table 1 reveals the predicted savings of an extensive simulation results by the Pacific Northwest National Laboratory (PNNL)[13] on 16 prototype building models.

[13] Pacific Northwest National Laboratory (2011), Achieving the 30% Goal: Energy and Cost Savings Analysis of ASRAE Standard 90.1-2010, prepared for the U.S. Department of Energy

Table 1-Average Energy savings achieved in different buildings by switching from ASHRAE 90.1-2004 to ASHRAE 90.1-2010 (Data adopted from report by Pacific Northwest National Laboratory[14])

Building Type	Building Prototype	90.1-2004 (kWh/m2)	90.1-2010 (kWh/m2)	90.1-2004 (kBtu/ft2)	90.1-2010 (kBtu/ft2)	Energy savings
Office	Small	130.2	103.4	41.3	32.8	20.6%
	Medium	162.7	117.6	51.6	37.3	27.7%
	Large	145.1	105.3	46	33.4	27.4%
Retail	stand alone	239.7	156.1	76	49.5	34.9%
	strip mall	253.5	179.4	80.4	56.9	29.2%
Education	Primary	231.5	158.3	73.4	50.2	31.6%
	Secondary	208.8	129.9	66.2	41.2	37.8%
Health Care	Outpatient health care	515.0	389.8	163.3	123.6	24.3%
	Hospital	496.4	373.4	157.4	118.4	24.8%
Lodging	Small	247.6	210.0	78.5	66.6	15.2%
	Large	516.9	397.0	163.9	125.9	23.2%
Warehouse	Warehouse	82.9	59.9	26.3	19	27.8%
Food Service	Quick service	1797.9	1639.5	570.1	519.9	8.8%
	Full Service	1292.0	1043.5	409.7	330.9	19.2%
Apartment	Mid rise	148.2	129.9	47	41.2	12.3%
	High rise	154.2	138.8	48.9	44	10.0%

According to this study[14], an average reduction in energy consumption of 25.6% can be achieved through the transition, with an average value of 10% in high-rise buildings and 12.3% in mid-rise buildings. This study also covered the simulation for different climate zones; the predicted values for Vancouver are shown in Table 2:

Table 2- The predicted energy savings achieved by switching from ASHRAE 90.1-2004 to ASHRAE 90.1-2010 within MURBs-Vancouver (Data adopted from report by Pacific Northwest National Laboratory[14])

Building Type	Energy Code	EUI Total (kWh/m2)	Energy savings (%)
Mid-rise	90.1-2004	142.5	
	90.1-2010	127.4	11%
High-rise	90.1-2004	141.0	
	90.1-2010	125.8	11%

[14] Pacific Northwest National Laboratory (2011), Achieving the 30% Goal: Energy and Cost Savings Analysis of ASRAE Standard 90.1-2010, prepared for the U.S. Department of Energy

Another simulation study conducted by EnerSys Analytics Inc. for MURBs[15], predicted the mentioned energy savings based on fuel type. The summary of results within MURBs is shown in Table 3.

Table 3- The predicted energy savings achieved by switching from ASHRAE 90.1-2004 to ASHRAE 90.1-2010 within MURBs –Lower Mainland (Data adopted from report by EnerSys Analytics Inc.)[15]

Building Type	Energy Code	EUI Elec. (kWh/m2)	EUI Gas (kWh/m2)	Total EUI (kWh/m2)
MURBs	90.1-2004	80.7	108.7	188.6
	90.1-2010	70.0	105.5	175.3
	Energy savings (%)	**13.3%**	**3%**	**7.02%**

A third study was done by Stantec Company[16] and predicted 10% reduction in energy consumption for an average mid-rise building (with retail units) located in south coast of British Columbia. As the first study done by PNNL is pretty detailed and specifically done for Vancouver climate zone (zone 5c according to ASHRAE), within this report the 11% increase in total energy savings will be assumed within MURBs, as a result of switching from ASHRAE 90.1-2004 to ASHRAE 90.1-2010.

2.4. Comparison with Energy Codes in other Regions

2.4.1. Heating Degree Days and Weather Normalization

In Canada, the highest proportion of total energy consumption in residential buildings is usually dedicated to space heating end use area. A major driver to such high levels of heating energy consumption is the climate conditions of the region of study. As a result, energy codes such as ASHRAE classify the regions based on their "Heating Degree Days" (HDD) and set specific energy requirements for each region. Based on the definition by National Weather Services of US, "Degree days is a quantitative index demonstrated to

[15] EnerSys Analytics Inc (2011) Summary Review Assessment of Energy Performance Codes , ASHRAE 90.1-2004, 90.1-2010 and NECB for British Columbia.
[16] Stantec Consulting Ltd. (2012). BC Energy Code Comparison (Final report), Version 4, Project Number: 115601742

reflect demand for energy to heat or cool houses and businesses" [17]. Heating Degree Days, derived from continuous measurement of outside temperature, is thus the number of degree days that a building requires heating throughout a year. Different numbers are used in the literature as the base outside temperature above which a building needs no heating. According to Natural Resources Canada[18], 18°C (65°F) is commonly used in Canada as the base for HDD calculations.

ASHRAE energy code classifies different regions into 8 climate zones based on their HDD. British Columbia covers 4 of these zones, as shown in Figure 1. Lower Mainland falls into climate zone 5 according to Figure 1.

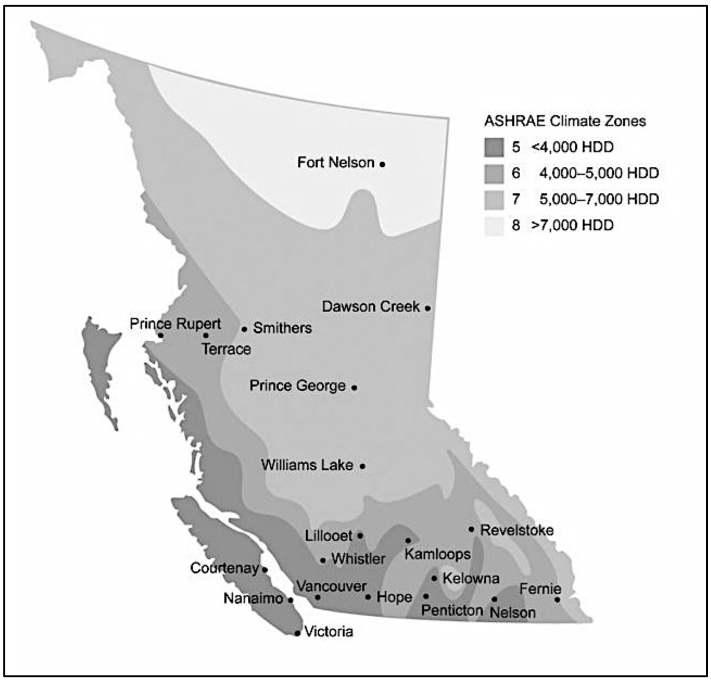

Figure 1- ASHRAE 90.1 classification of climate zones within British Columbia[19].

In order to compare building energy use intensity in Lower Mainland with EUI data from other regions, normalization of energy consumption data with HDD is essential; Otherwise the results would be misleading since higher energy consumption is expected for extremely

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[17] Explanation of the weekly and monthly degree day data summaries (2005), Retrieved from (National Weather Service Climate Prediction Centre) http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml
[18] Energy Use Data Handbook from 1990 to 2008 (2011), Retrieved from (Natural Resources Canada) http://oee.nrcan.gc.ca/publications/statistics/handbook10/appendixc.cfm
[19] Figure adopted from RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia

cold or hot climates compared to milder climates due to the significance of cooling or heating loads.

2.4.2. General Status in Regions[20]

EUROPE

In 2002, the Directive on the Energy Performance of Buildings (EPBD) was adopted in the European Union as the base regulation for energy efficiency in buildings, which must be implemented by all member states.

This directive[21] mandates all members to establish their own standards of energy efficiency within their new construction programs, based on energy performance of the building. The calculated performance is expected to include the following parameters:

- Thermal characteristics of the building (shell and internal partitions, air-tightness, etc.)
- Heating installation and hot water supply (including insulation characteristics)
- Air-conditioning installation
- Ventilation
- Position and orientation of the buildings (including outdoor climate)
- Passive solar systems and solar protection
- Natural ventilation
- Indoor climatic conditions (including the indoor design criteria)

Also any positive effect of implemented renewable energy sources, district energy systems or natural daylight has to be taken into account.

Furthermore, the directive obliges all new buildings to be certified, this certification can be accomplished during design or after construction. Another aspect of this directive comprises the required inspection of heating/cooling systems of the building.

There are other directives (Eco-Design Directive, Directive on Energy end-use and Energy Services…) that set demands for labeling of different appliances /products, energy services and energy efficiency activities; these have a large impact on energy efficiency of buildings.

[20] This section is mainly retrieved from "Energy Efficiency Requirements in Building Codes" by Laustsen, J. (2008)-IEA Information Paper, International Energy Agency

[21] DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0065:EN:PDF

In 2011, the European Commission approved the "Energy Efficiency Plan 2011"[22] for saving energy through more concrete measures. Another initiative made by the European Commission is assigning the European Standardization Organization to develop standards for calculating the different parts of the building energy performance. The aim is to consolidate the different methodologies in European countries.

However, up to now a common standard for all EU countries has not yet been set and the levels for energy efficiency standards vary considerably.

For example in Sweden, rigorous requirements for energy efficient buildings were hosted since 1970s. Regulations set values for equipment efficiencies, ventilation and other thermal comfort parameters as well as the overall energy performance for the building. Values differ by location (north or south of Sweden) and building type (residential, commercial, etc.) The maximum allowable values for building performance or insulation of envelope are very low, close to the Passive House Standards[23]. The most interesting part is that actual consumption of the building has to be documented and satisfy the set values.

North America

In both US and Canada, states or provinces are responsible to set and enforce minimum standards for energy efficiency in buildings. The energy efficiency requirements fluctuate significantly among the states. ASHRAE is the main standard which is adopted by most states for residential/commercial buildings but the adopted levels might be different (e.g. British Columbia uses 2004 version of ASHRAE 90.1).

Japan

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is in charge of setting and controlling energy efficiency standards for buildings, as part o the national Energy Conservation Law (first adopted in 1979). Design and Construction Guidelines on the Rationalisation of Energy Use for Homes set the energy efficiency requirements for residential buildings with two approaching options of prescriptive and performance model.

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[22] European Commission, Energy Efficiency Plan 2011.

[23] The passive house standard was first defined in 1988 by Dr. Wolfgang Feist from Germany and Professor Bo Adamson from Lund University of Sweden, currently the passive house institute in Darmstadt is in charge of setting and controlling the regulations. The set values in this standard are dedicated specifically to central European climate (with dominant heating season).

The Criteria for Clients on the Rationalisation of Energy for Buildings regulates the energy efficiency in commercial buildings and high-rise residential buildings which is based on energy performance or energy frame values (PAL and CEC values[24]). Green Building Ratings are being conducted by CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) which is considered a voluntary system.

The Japanese standards have directed the industry to implement high energy efficient appliances/equipment within buildings as well as very efficient installations. Equipment efficiency is further promoted by labeling standards and Top Runner schemes (a Japanese system to encourage producers to develop and implement energy efficient systems.)

Australia, New Zealand

Australia's national government has set regulations for energy efficiency in new buildings which has to be adopted by the federal states for being. Minimum energy efficiency provisions were introduced through the BCA (Building Code of Australia) in 2003 for housings. In 2010, BCA has obliged new commercial and public buildings "to achieve a level of performance in line with the Council of Australian Governments (COAG) target of a 2:1 benefit to cost ratio"[25]. Moreover, a 5-stars system (recently 6-stars system for part of buildings) for rating energy efficiency in both residential and commercial buildings exists. For example, in the state of Victoria, all the 5 stars are compulsory as the mandatory minimum requirement, which is considered an effective way of promoting highly efficient buildings.

2.4.3. Comparison of Building Envelope Energy Requirements in Different Countries

No energy study comparing the EUI for MURBs in different countries was available in the literature, since the demands are highly dependent on local traditions and on climatic

[24] The PAL values (Perimeter Annual Load) are set for the performance of the building envelope (in $MJ/m^2/yr$), while CEC values (Coefficient for Energy Consumption) are factors determining the efficiency of equipment and appliances such as HVAC systems, ventilation (V), lighting (L), hot water (HW) and the elevator (EV).
[25] Retrieved from The Australian Building Codes Board, http://www.abcb.gov.au/major-initiatives/energy-efficiency/multi-residential-commercial-and-public-buildings

conditions in individual countries or states[26]. The only metrics that could be used for comparison of the energy consumption in different countries is the performance of building envelope based on the U-values for roofs, walls, windows as well as the overall performance. The International Energy Agency performed a comprehensive energy study[26] in March 2008, comparing current approaches to energy efficiency requirements by standards and codes for residential buildings in different countries including developed countries such as Japan, Australia, Europe and North America, and developing countries such as China and India. This study focuses only on cold and heating based countries, covering majority of Europe, a significant portion of Canada and US, as well as a large area of Japan, Southern Australia and New Zealand. The U-values are normalized with HDD for comparison purposes. Figure 2 shows the comparison between U-values of (A) Ceilings, (B) Floors, (C) Walls, and (D) Windows for the mentioned regions. Values are shown as a function of modified HDDs. Please note that lower U-values are more desirable as U-value is an indicator of heat transfer extent. Significant differences exist in U-value requirements between different countries. According to Figure 2, ASHRAE 90.1 (2004) requirements are similar or slightly better than European codes for ceilings, walls and floors. However, a notable difference is observed in Figure 2 (D) where the requirements for windows are higher in Europe than in North America. This difference affects the overall U-values of buildings, shown in Figure 2 (E), and gives European countries a better standing compared to North America in terms of building envelope energy performance.

The findings of this study, discussed in Section 4, appear to be in line with the conducted analysis by International Energy Agency, in that the importance of increasing glazing efficiency in North America, especially regions with high glazing ratio such as Lower Mainland is evident in both of the studies.

Note that these results are subject to change over time and more up-to-date studies are favorable though not currently available.

[26] Laustsen, J. (2008). Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, IEA Information Paper, International Energy Agency

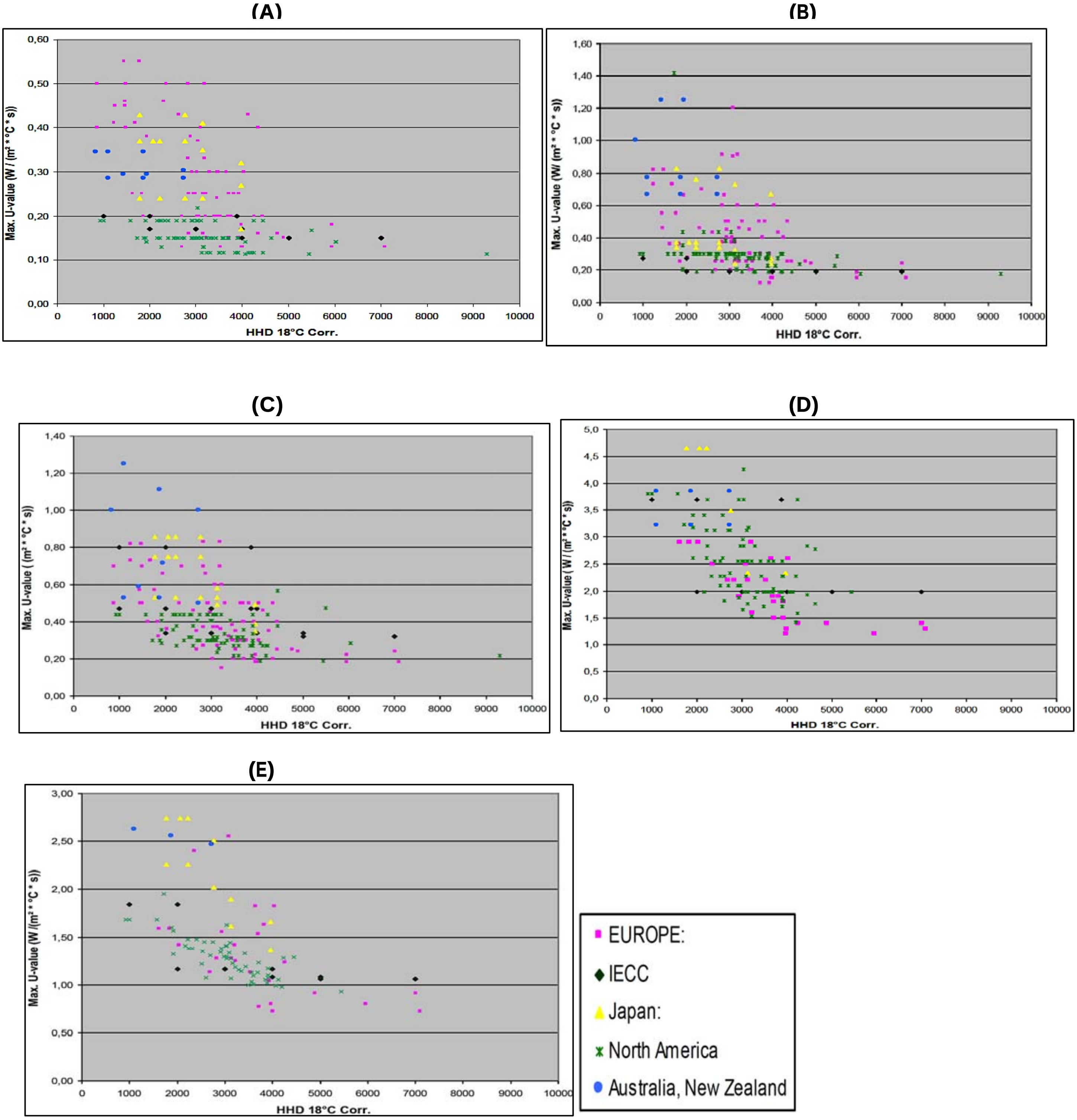

Figure 2. U-values for (A) Ceilings (B) Floors (C) Walls (D) Windows and (E) Overall for selected countries with heating based climates (Figure adapted from: Laustsen, J., (2008). Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, IEA Information Paper, International Energy Agency.)

3. METHODOLOGY

Baseline and proposed energy consumption data from energy modeling of 6 residential mid- and high-rise buildings, listed in Table 4, were provided by the sponsor for this study, BC Hydro Power Smart. Similar energy study results had also been made available for other applications such as hospitals, educational institutions, etc.; however these studies were only analyzed for comparison purposes (See Section 4.1) as the major focus of this study was on MURBs. High-rise buildings were designed under ASHRAE 90.1 (2007) energy code, while mid-rise MURBs followed the requirements of ASHRAE 90.1 (2004). All buildings had received financial incentives under BC Hydro Power Smart New Construction Program (NCP). BC Hydro NCP has been established to boost the production of new high performance and energy efficient commercial, institutional and multi-unit residential buildings in BC. One of the major objectives of NCP is to encourage the mainstream design and development industry to adopt integrated design process and building performance modeling as standard practices, which consequently has the potential to create high-performing and energy efficient buildings at lower cost[27]. The financial incentives provided by NCP help developers and their design teams to overcome financial barriers of high energy performance building especially in early design stages. Three categories of tools and incentives offered by NCP include: “Whole Building Design” for modeling the building as an integrated system, “System Design” for specific systems where energy modeling is not cost-effective, and “Energy Efficient Lighting Design” for more efficient lighting performance.

[27] Consultant Orientation Manual (2011). Retrieved from (BC Hydro) http://www.bchydro.com/content/dam/hydro/medialib/internet/documents/power_smart/builders_developers/A11_137_new_construction_program_manual.pdf

Table 4- Specifications of the studied buildings

Building ID	Building Type	Total Area (m^2)	Total AC area (m^2)	Energy Code	Location	Mechanical Systems
A	Residential High-rise	10,450	10,450	ASHRAE 90.1 (2007)	Vancouver	Air-Source Heat Pump/ gas for DHW
B	Residential High-rise	16,707	10,809	ASHRAE 90.1 (2007)	Vancouver	Variable Refrigerant Flow System with boiler
C	Residential High-rise	8,436	5,625	ASHRAE 90.1 (2007)	Vancouver	Air-Source Heat Pump with back-up boiler
D	Residential Mid-rise	10,206	8,436	ASHRAE 90.1 (2007)	Vancouver	Water-Source Heat Pump with back-up boiler
E	Residential Mid-Rise	68,220	68,220	ASHRAE 90.1 (2004)	Richmond	Heat Pump w/ condensing boiler for DHW
F	Residential mid-rise	13,795	9,650	ASHRAE 90.1 (2004)	Vancouver	No Available Data

3.1. ENERGY USE INTENSITY

Energy breakdown of different buildings were available in the end use tables provided by BC Hydro. As the focus of this report is on MURBs, except a brief comparison on average EUI of buildings with different applications, the rest of analysis is dedicated to residential buildings. This includes three high-rise and two mid-rise buildings, since data was missing for one of the 3 provided mid-rises.

For each building, energy use intensity of both electrical consumption (kWh/m^2) and gas consumption (GJ/m^2) was calculated based on the air-conditioned area. For the purpose of comparability and using a standard unit, the gas data were converted to ekWh whenever necessary (1 GJ=277.78 kWh); however, in most of the comparisons, effort has been made to make a separate analysis on electrical and gas data, as this is of specific interest of this report and also they have different environmental impacts. Once building performance has been identified, the saving intensities (ekWh/m^2) could be calculated versus the building baseline energy intensity.

As transition should be made towards ASHRAE 90.1 (2010) in near future, a literature review on the estimated reduction in energy consumption, specific to residential sector, has been conducted. An archetype building performance has been made to estimate the future baseline for current practices in new construction programs. Next, for each building, the relevant 2010 baseline has been shown to find the approximate gap and the potential areas for further action. See Section 4 for more details on data analysis.

3.2. GREENHOUSE GAS EMISSIONS

In general, the sources of energy for operating a residential building are natural gas and electricity: Natural gas has direct GHG emissions while electric-based power supply is considered to have indirect emissions. The associated emissions should be reported as per Carbon Neutral Government Regulation, B.C. Reg. 392/2008. British Columbia benefits from having "clean "electricity produced mainly from its vast hydroelectric dams. Considering this fact, buildings within BC have lower Carbon footprint not essentially as a result of best practice.

The emission factor for natural gas is 49.86 kg CO_2/GJ[28], but determining the emission factor for electricity is more complicated, especially for future construction programs: In hydroelectric resources, the water supply may fluctuate significantly each year and this will affect the "green" share of available electricity; BC Hydro as the main supplier for Vancouver, annually tracks the GHG emissions of its supply and reports it as part of Global Reporting Initiative (GRI) Index.

The current emission factor for purchased electricity from BC Hydro (0.025 kgCO2/ kWh) is based on their reported average GHG intensity values from 2008 to 2010[25] (available data from the most recent period).

The RDH Company has stated in their report[29] that within BC (with a mixed resource for electrical supply) the emission factor for electricity is 0.055 kgCO_2/kWh, according to NRCan. On the other hand, a marginal value of 0.36 kgCO_2/kWh has been suggested by the Ministry of Energy, Mines and Petroleum Resources (MEMPR) until 2016, to account for the current electricity purchase from Alberta. In this report, GHG emission from electricity is based on the proposed factor by BC Hydro (0.025 kgCO2/ kWh).

[28] Ministry of Environment, (2012) BC Best Practices Methodology for Quantifying Greenhouse Gas Emissions
[29] RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia, *Final Report*

3.3. Energy Conservation Measures (ECMs)

An Energy Conservation Measure (ECM) is any type of project conducted or technology implemented to reduce the consumption of energy in a building. The aim of an ECM should be to achieve a saving by reducing the amount of energy used by a particular process, technology or facility[30]. Normally more than one ECM is utilized in new construction residential projects. The assembly of different ECMs together is called a “Bundle”. According to U.S. Department of Energy[31], bundling many energy conservation measures (ECMs) together can result in lower rates and more conservation for each dollar invested. Greater facility improvement can be achieved when ECMs with longer-term payback periods are bundled with and offset by those with shorter payoff terms. It should be noted that due to diverse configurations of each ECM bundle in this study, comparison of energy savings achieved from different bundles was not feasible. Therefore, for the purpose of this study, the ECMs are studied individually.

3.4. List of ECMs in this Study

Twelve different ECMs were investigated in this study. Table 5 below represents these ECMs along with their adoption rates (i.e. the percentage of studies in which the particular ECM was utilized) and a brief description of each.

[30] Energy Conservation Measure (2013), Retrieved from (Wikipedia) http://en.wikipedia.org/wiki/Energy_conservation_measure
[31] Ten Ways to Lower Perceived Risk and Finance Rates within Utility Contract (2011), Retrieved from (US Department of Energy) http://www1.eere.energy.gov/femp/financing/uescs_tenways.html

Table 5-ECMs, percentage of adoption, and a brief description

Energy Conservation Measure	Percentage of Adoption within the study (%)	Description
Interior LPD[32] Reduction	66%	• Decreasing Watts/m² of interior lighting by switching to more efficient lighting e.g. LED, CFL, T8 fluorescent • BC Hydro provides incentives of $150 to $200/suite for installing Energy Star® appliance and CFL for new MURBs[33] • Minimal baseline targets for BC Hydro lighting requirements: Minus 10% of the following codes: • MURBs outside the City of Vancouver → ASHRAE 90.1. 2004 • MURBs inside the City of Vancouver → ASHRAE 90.1. 2010
Interior Lighting Control	83%	• Reducing lighting energy waste by turning off or dimming the interior lights when not needed • Could be utilized in parkades, stairways, and other low-occupancy areas • Turn on periods must be integrated with the space functionality • Part of additions to the code requirements in ASHRAE 2010
Exterior LPD Reduction	50%	• Decreasing Watts/m² of exterior lighting by switching to more efficient lighting e.g. High Pressure Sodium, Metal Halide • Covered by the Energy Efficient lighting Design Program by BC Hydro NCP Program
Exterior Lighting Control	16%	• Installation of daylight sensors for turning off the exterior lights with daylight • Installation of night lighting controls i.e. 30% reduction from 12 AM to business opening or 6 AM is part of additions to ASHRAE 90.1. 2010 requirements[34]

[32] LPD is defined as the Maximum lighting power per unit area of a building allowed by code according to the classification of space function. Illuminating Engineering Society of North America (IESNA) and ASHRAE 90.1 set standards for interior lighting levels in different areas of buildings.

[33] New Construction Program Energy-Efficient Lighting Design: Reference Guide for Lighting Calculator, Version 2.7 (2010). Retrieved from (BC Hydro Power Smart) http://www.bchydro.com/content/dam/hydro/medialib/internet/documents/psbusiness/pdf/ps_business_-_hpb-eeld.pdf

DHW Low Flow Fixtures	33%	• Energy savings are achieved by decreasing domestic hot water consumption compared to average fixtures via low flow fixtures such as low-flow shower heads
DHW Heating/pre-heating	33%	• The system utilizes waste heat e.g. from exhaust air or return sanitary water to preheat domestic water before entering into the boiler
High Efficiency HVAC Systems	100%	• HVAC is a high-potential energy saving area due to its significant share of energy consumption in MURBs • Air cooled VRF system, central air to water heat pump and condensing boiler, and high efficiency makeup air unit (MAU) were among the ECMs for HVAC efficiency within the study
Variable Frequency Drive (VFD)	33%	• VFDs and Variable Speed Drives (VSDs) are utilized in order to adjust motor output speed by varying input frequency and voltage • Energy Savings are achieved since motors do not operate at their 100% capacity all the time • Examples of VFDs utilized in the study are VFD fans on parkade exhaust fans and VSDs on pumps
Roof Insulation Increase	83%	• Includes increasing thermal resistance of the building roof compared to requirements of ASHRAE 90.1 • Thermal resistance is a heat property and a measure of a temperature difference by which an object or material resists a heat flow[35] • High thermal resistance is desirable for building envelope
Wall Insulation Increase	83%	• Includes increasing thermal resistance of the building roof compared to requirements of ASHRAE 90.1
High Efficiency Glazing	83%	• Lower heat losses, warmer window surfaces, and reduced air leakage are among characteristics of high efficiency windows[36] • Majorly feature double, triple or quad (in rare cases) glazing, insulating gas such as Argon between panels, reducing the U-factor and heat transfer.
Shading	83%	• Shading reduces sun penetration from windows and

[34] Stantec Consulting Ltd. (2012). BC Energy Code Comparison (Final report), Version 4, Project Number: 115601742

[35] Thermal resistance (2013). Retrieved from (Wikipedia) http://en.wikipedia.org/wiki/Thermal_resistance

[36] Ander, G.A. (2012), Windows and Glazing, Retrieved from (National Institute of Building Science, Whole Building Design Guide) http://www.wbdg.org/resources/windows.php

	other glass areas in summer while letting the sun inside the building in winter • Design requires complicated models with three dimensional simulation

3.1. Cost/benefit Analysis: Terminology & Assumptions

A cost/benefit analysis has been conducted in this study and the results are shown in Section 4. The following section presents the basic terminology as well as the assumptions made for the financial analysis.

3.1.1. Simple Payback Period

Simple Payback Period (SPP) refers to the period of time required for the return on an investment to "repay" the sum of the original investment. All else being equal, shorter payback periods are desirable compared to longer ones[37]. This term is widely used in energy efficiency and sustainability fields. It should be noted that simple payback period provides an incomplete view of an investment's financial return and can lead to sub-optimal decision making by not incorporating the time value of money[38]. SPP can be calculated through the following equation:

$$Payback\ Period\ [years] = \frac{Initial\ Investment}{Cash\ Inflow\ per\ period}$$

In order to overcome the limitations of SPP, other financial metrics such as Net Present Value could be employed.

[37] Payback Period (2013). Retrieved from (Wikipedia) http://en.wikipedia.org/wiki/Payback_period
[38] Re-thinking Simple Payback Period (2009), Retrieved from (BetterBricks) http://www.betterbricks.com/office/briefs

3.1.2. Net Present Value (NPV)

Since money has a time value, the Present Value (PV) is defined as the current worth of a future sum of money given a specified discount rate[39]. Higher discount rates result in lower present values of future cash flows. Net Present Value is the difference between the capital cost, which usually happens in the present and does not require discounting, and the present value of cash inflows i.e. energy savings. The assumptions for NPV calculations are discussed in the following section.

3.1.3. Fuel Escalation Rate and Real Discount Rate Assumptions

Historical trends of electricity and natural gas prices worldwide show that energy prices are subject to change over time, which makes it essential to consider the possible energy price changes in future. However, it should be noted that there is a high level of uncertainty associated with any forecast of future energy prices. An escalation rate of 4% for future prices has been assumed for this study. The discount rate for determining the NPV of cash flows has been assumed to be 5%, which is below the real discount rates for similar energy studies[40] as part of a conservative approach.

3.1.4. Electricity and Natural Gas Rates for MURBs

Electricity in BC is sold under two different rate classes: Residential rates and Commercial rates. All electricity consumed by individual suites and metered by individual meters fall into the residential rate category, while commercial rates apply for electricity used in common areas and metered via a common meter. A stepped rate is applied by BC Hydro to Residential electricity consumption under rate schedule 1101[41]. As of April 1st 2012, BC Hydro charges residential costumers 6.80 cents per kWh for the first 1,350 kWh, and 10.19 cents per kWh for all electricity used beyond that threshold. Natural Gas used to fuel common boilers and hot water tanks in residential MURBs is sold under a commercial Rate.

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[39] NPV Calculation (2010), Retrieved from (Illinois Institute of Technology) http://www.iit.edu/arc/workshops/pdfs/NPV_calculation.pdf

[40] Compass Resource Management Ltd. & EnerSys Analytics Ltd. (2008). Costs and Benefits of Energy Efficiency Measures for High Rise Multi-Unit Residential Buildings and Row house Units in Surrey, BC.

[41] Residential Rates (2013), Retrieved from (BC Hydro) https://www.bchydro.com/accounts-billing/customer-service-residential/residential-rates.html

Fortis BC Rate 2 normally applies to apartment buildings with less than 2000 GJ consumption annually[42]. Accounting for daily basic charges, delivery charges, midstream charges and cost of gas, residential building customers are currently being charged approximately $8 per GJ[43].

4. Results and Discussion

4.1. Energy Consumption

Energy consumption of the buildings with different applications, normalized to the area, is shown in Table 6 and Figure 3 below. As expected, the most energy intensive buildings are hospitals and retail stores due to their high process/plug loads and their end use service. The next range (134-200 ekWh/m^2) belongs to residential sector including high-rise, mid-rise and mixed use (commercial/residential) buildings. The relatively high portion of gas consumption observed in high-rise buildings is comparable to gas consumption in hospital/health care applications whereas the total energies are not analogous.

Table 6- Average Energy Use Intensity of Buildings With Different Applications

Building Type	Total Energy Use Intensity (ekWh/m^2)		
	Elec. EUI	Gas EUI	Total EUI
High-rise Buildings	116.65	82.59	199.24
Mid-rise Buildings	100.54	33.43	133.97
Mixed use	125.56	20.55	146.11
Offices	146.13	10.52	156.65
Retail	213.16	27.10	240.26
Hospital/Health care	241.28	104.30	345.58
University/college	95.72	18.61	114.33
Schools	83.20	16.43	99.63

[42] Lower Mainland Rates for Business and Industry (2013), Retrieved from (FORTISBC) http://www.fortisbc.com/NaturalGas/Business/Rates/LowerMainland/Pages/default.aspx
[43] Lower Mainland Rate 2 (2013), Retrieved from (FORTISBC) http://www.fortisbc.com/NaturalGas/Business/Rates/LowerMainland/Pages/LMRate2.aspx

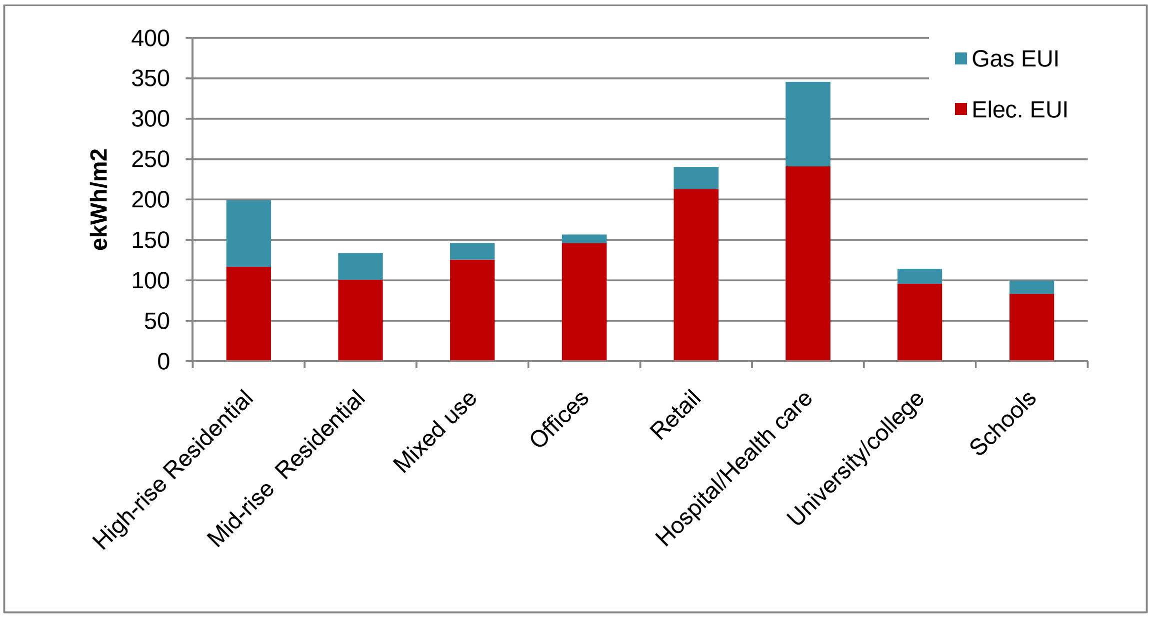


Figure 3-Average Energy Use Intensity of Different Buildings (ekWh/m²)

Another point to mention is the higher share of electricity (>60%) in MURBs in contrast to what is historically observed (49% of the total)[44].

This is considered as a result of adopting heat pumps for space heating/cooling instead of conventional baseboards, which were just providing space heating; electrical demand will also increase due to operation of additional fans, pumps and compressors. Another aspect of utilizing heat pumps during heating season is the required backup system (gas boiler) in case of extremely cold conditions.

The higher level of gas consumption might also be caused by higher level of convenience and more amenities in more recent high-rise buildings. As detailed design information of the studies was not available, the actual reason cannot be determined here.

4.1.1. Energy Consumption in each end use area

Energy breakdown of end use areas is displayed in Table 7, Figure-4 and Figure-5.

[44] RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia, *Final Report*

Table 7- Energy Breakdown Data in an Average MURB

END USE Area	Total Energy Use Intensity (ekWh/m²)	Total Energy Savings (ekWh/m²)	Percentage of Savings Versus Total Saving
Space Heating	31	23.04	61.6%
Space Cooling	5	-2.34	-6.3%
Fans	10	2.16	5.8%
Pumps	7	2.81	7.5%
DHW	37	7.49	20.0%
Plug Load	16	0.00	0.0%
Elevators	11	0.00	0.0%
Interior Lights	28	3.65	9.8%
Exterior Lights	2	0.56	1.5%
Total	**146**	**37**	**100%**

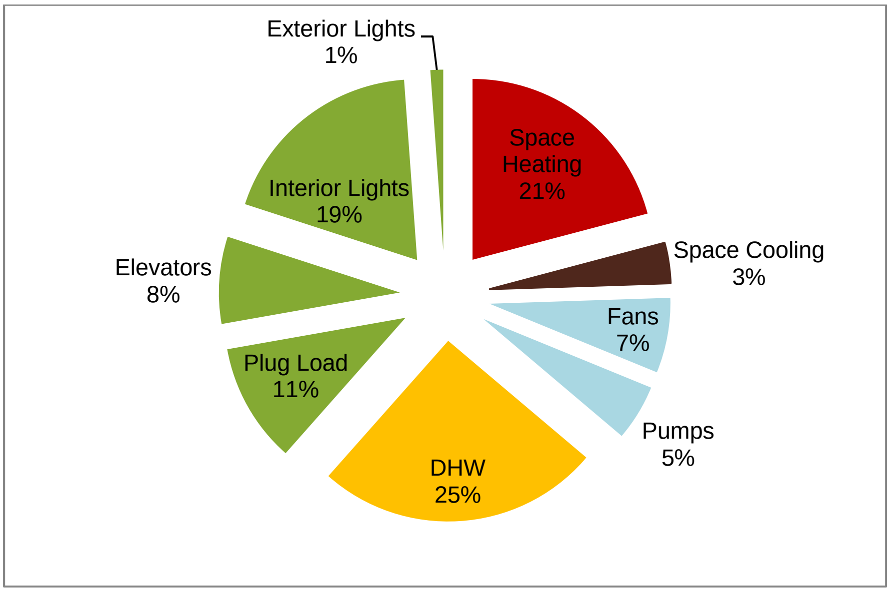


Figure 4. Breakdown of Energy Consumption in An Average MURB (Percentage of Total Energy Consumption)

As displayed in Figure-4, required energy for domestic hot water, space heating and interior lights account for about 65% of the total energy consumption in an average MURB. Lighting is purely dependent on electrical supply whereas both DHW and space heating have a mixed share of natural gas and electricity sources. Figure-5 shows that majority of proposed savings, compared to the current baseline, is focused in space heating end use area.The second rank for proposed savings belongs to DHW area (which is mainly achieved by utilizing low flow fixtures as will be explained in Section 4.3) and the third rank belongs to interior lighting.

Negative saving in the area of space cooling (Figure-5) with respect to the baseline, might be considered as a result of poor enclosure design and implementing heat pump systems in new design practices. Normally space cooling was not provided in conventional residential buildings due to mild climate of Vancouver; it is assumed that utilization of heat pumps within newly constructed MURBs encourage more demand during cooling season instead of trying to build a passive enclosure with less solar gain in summer.

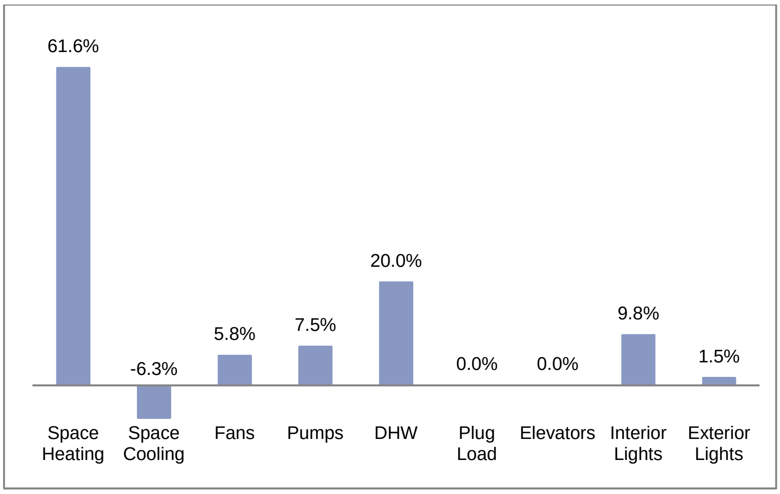


Figure 5-Percentage of Average Energy Savings Achieved in each end use area Compared to The Current Baseline

4.1.2. ENERGY CONSUMPTION IN DIFFERENT MURBS

Considering Table 1 for building specifications, energy consumption (normalized to the air conditioned area) of each of those building is tabulated in Table 8.

Table 8- Total Energy Use Intensity of studied buildings in each end use area (ekWh/m²)

		Total Energy Use Intensity (ekWh/m2)				
	End Use Area	Building A	Building B	Building C	Building D	Building E
1	DHW	6.07	87.81	98.11	4.54	26.20
2	Space Heating	11.42	45.36	59.68	13.91	53.08
3	Space Cooling	2.06	1.14	14.05	3.35	11.14
4	Fans, pumps	12.61	6.70	53.45	11.74	18.26
5	lights/elevator/plug load	50.58	97.76	50.94	62.09	63.63
	Total	**82.75**	**238.76**	**276.22**	**95.64**	**172.30**

For the purpose of understanding the consumptions directly related to mechanical systems, the pure electrical consumptions (lighting, plug load, elevator) is accumulated in one category (Item 5 of Table 8). Consumption in this category is highly influenced by cultural and behavioral dimensions as well as the system efficiency. The first two end use areas (DHW and space heating) have a mixed use of electricity and gas and the consumption is tied to the selected mechanical system for either heating of air or water. However, DHW consumption is completely independent of building envelope design whereas space heating demand is highly affected by that. The consumption in space heating/cooling and fans/pumps end use areas is directly related to the building form and orientation, enclosure performance, glazing ratio and system efficiency. Figure-6 reveals the stated data in previous table.

The most obvious observation of Figure.6 is the significant fluctuations of energy consumption even among the first three high rise buildings which have adopted the same baseline (ASHRAE 90.1-2007). These major differences might be related to the buildings amenities (data was not available for this study).

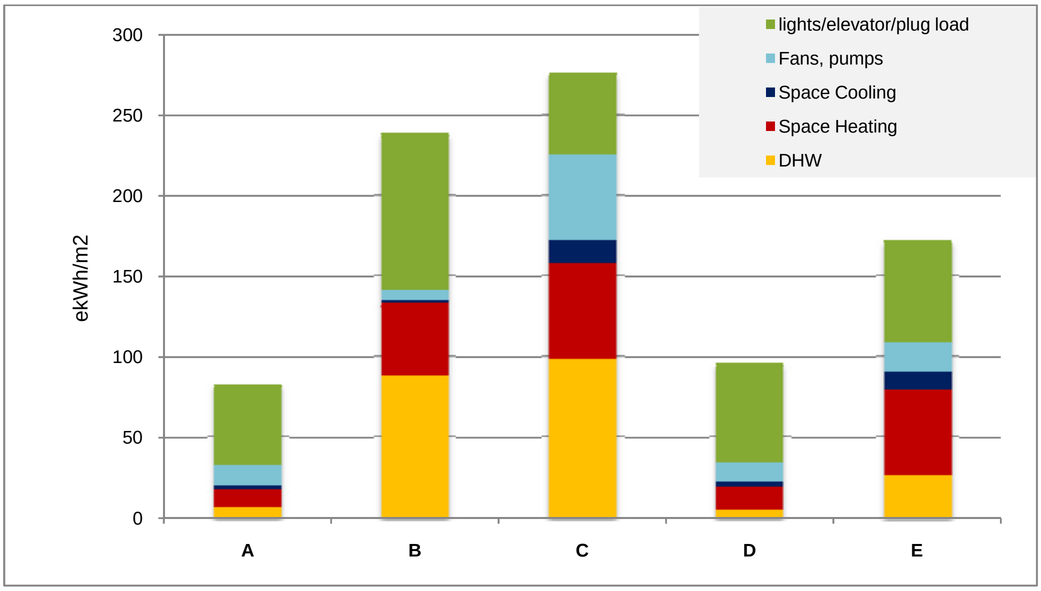


Figure 6-Energy Use Intensity of Each Residential Building

The significantly high energy intensity in space cooling, fans and pumps end-use areas for Building C suggests a low performance building envelope and/or high glazing ratio in this building. Furthermore, the highest hot water consumption observed in the same building (most probably for a swimming pool demand) could be due to relatively higher level of convenience in this building. This highlights the importance of considering building amenities when analyzing the energy performance of residential building.

Considering the limited available design information, at best, we can conclude that firstly transition from conventional boilers to district energy systems, heat pumps (for hot water) or at least condensing boilers for space heating will result in higher energy efficiency, especially in high-rise buildings. Secondly, installation of hydronic panels as the final energy technology instead of all air systems will improve the overall efficiency due to higher area of heat transfer. Thirdly, reducing glazing ratio, providing outside window shutters and well-designed shadings will reduce the energy demand during cooling season.

4.1.3. Energy Performance of Each Study MURB Versus Baseline

The intensities of each building energy consumption and baseline consumption are summarized in Table 9, with the last column presenting the percentage of achieved savings within each building compared to its adopted baseline. Note the negative savings of natural gas for buildings C and E means that the performance is below the level predicted by its baseline. These energy wastes have been occurred in the space heating end use areas where it seems the gas consumption is higher than the value expected by the baseline. Note that just for building E the adopted baseline is the 2004 version of ASHRAE 90.1, whilst the rest are compared to the 2007 version, which further reveals the low performance of building E that most probably is due to a poor enclosure.

Table 9-Energy Performance of Study MURBs versus Their Adopted Baseline

Building ID	Energy Use Intensity (ekWh/m²)			Baseline Intensity (ekWh/m²)			% of savings versus baseline	
	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas
A	79.05	3.69	82.75	126.78	12.39	139.17	38%	70%
B	129.65	109.12	238.76	181.98	109.91	291.90	29%	1%
C	141.26	134.96	276.22	175.68	122.77	298.45	20%	-10%
D	92.97	2.67	95.64	122.19	5.66	127.86	24%	53%
E	108.11	64.19	172.30	136.64	57.96	194.61	21%	-11%

For the purpose of comparing current performance of buildings with ASHRAE 90.1 (2010), the approximate EUI of the buildings has been predicted as if they were built according to ASHRAE 90.1-2010. This is a very rough estimate as the accurate approach requires accomplishing an energy modeling of the buildings to account for all the itemized prescriptions of ASHRAE 90.1 (2010).

Based on studies in this field, as described in Section 2-3, an 11% reduction[45] in building total energy consumption has been predicted for switching from ASHRAE 2004 to ASHRAE 2010 for MURBs in Vancouver. It should be stated here that as no modelling result was found for the predicted performance change of an archetype building from ASHRAE 2007 to ASHRAE 2010, the mentioned value of 11% has been applied to the present study to foresee an approximate value of future baseline. This will not deviate the results significantly as the average predicted change from ASHRAE 2004 to ASHRAE 2007 is 5%, which is small compared to the expected 25% reduction from ASHRAE 2007 to ASHRAE 2010; focusing on

[45] Pacific Northwest National Laboratory (2011), Achieving the 30% Goal: Energy and Cost Savings Analysis of ASRAE Standard 90.1-2010, prepared for the U.S. Department of Energy

residential buildings with 11% reduction in switching from ASHRAE 2004 to ASHRAE 2010, the share of changes from ASHRAE 2004 to ASHRAE 2007 will be much smaller.

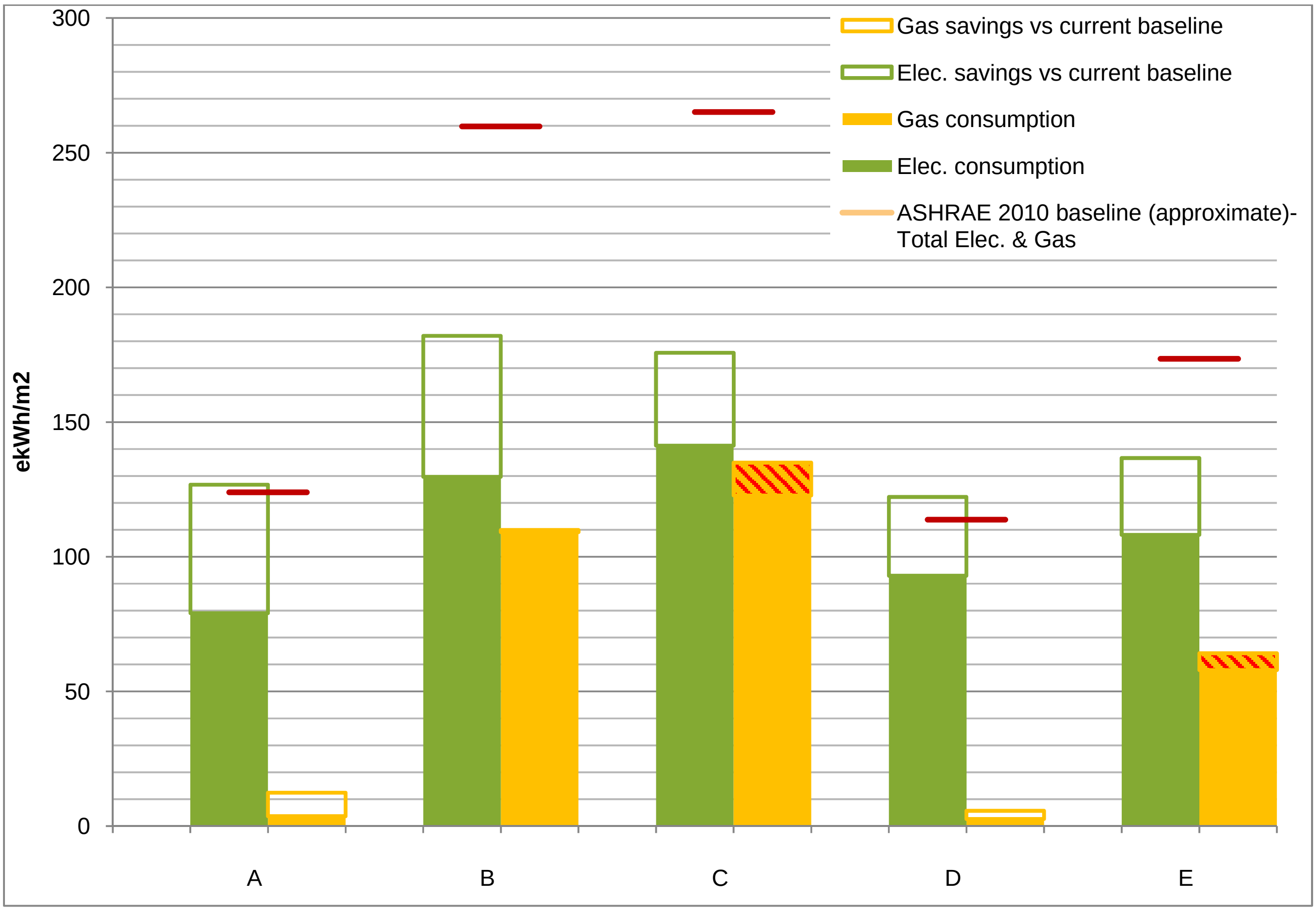


Figure 7-Energy Use Intensity (full bars) of Each Building Compared to Current (empty bars) and Future Baseline (lines) [Note 1: The hatched areas for buildings C&E show the exceeded consumption versus the building current baseline, Note 2: while comparing the current consumption (full bars) to future baseline (lines), note to consider the total of adjacent bars (Elec. and Gas)]

As shown in Figure 7, the current status of electrical consumption is acceptable compared to gas consumption; however more conservation measures should still be explored in the area of electricity as these guidelines set the minimum required performance. A very fluctuating trend is apparent in gas consumption, even exceeding the current baseline in some cases (buildings C & E). The only buildings which perform better than their current baselines are A and D, with 70% and 53% savings respectively. Others performs very close (buildings B and D) or worse (building D) compared to the future baseline. This chart mainly suggests focused action on strategies which will result in significant reduction in gas consumption, which could be translated to further conservations in DHW and space heating end use areas beyond the code.

Best practice among these buildings might be picked as Building A for high-rise buildings and building D in mid-rise buildings and buildings with high gas consumption (C and E) are expected to reveal issues with future baseline.

To have an overall picture of building energy performance, the values presented in Figure-7 are represented separately in Figures 8 and 9 for average high-rise and mid-rise applications. The total consumption of conventional practice in MURBs[46] has also been added to these charts. A summary is presented in Table 10.

Table 10- Average Energy Use Intensity in MURBs: Past, Present, Future

	High-rise buildings		Mid-rise buildings	
	Electricity	Gas	Electricity	Gas
Current Baseline	161.5	81.7	129.4	31.8
New Design	116.7	82.6	100.5	33.4
Future Baseline[47]	216.4		143.5	
Conventional Design[43]	213.0		239.0	

Comparing Figure 8 and 9, it is observed that new design practices for mid-rise buildings are capable of improving their performance much better than the high-rise buildings. Gas consumption in both types of buildings is higher than the current baseline which should be resolved.

In high-rise buildings, the relatively high reduction in gas consumption (~41% of the total) against conventional design (51% of the total)[48] is associated with higher ratio of electrical consumption (59% versus 49% of the total consumption for new and conventional design, respectively). This could be related to usage of heat pumps instead of electrical baseboards.

[46] RDH Building Engineering Ltd. (2012). Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia, *Final Report*

[47] Assumed 11% reduction in energy consumption based on modeling result by PNNL

Caution must be taken when comparing current energy performance to future baseline, as the predicted values are uncertain and the 11% reduction in energy consumption has been taken from other simulation results as explained before; However, it seems that due to relatively low share of the expected reduction in residential sector (compare 11% to 30%) and the incentives made by BC Hydro NCP, the overall performance of these buildings compared to ASHRAE 2010 is acceptable (except concerns with gas consumption). Nevertheless, these baselines are considered as minimal requirements and encouraging/enforcing conservations beyond the code are necessary to keep the declining trend.

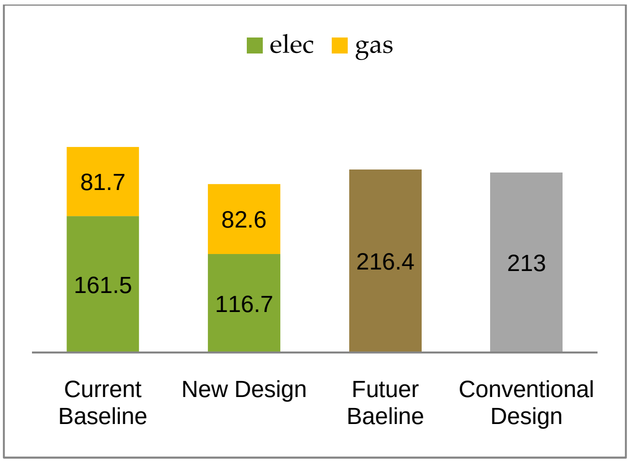


Figure 8-Approximate Trend of energy consumption in high-rise buildings, ekWh/m²

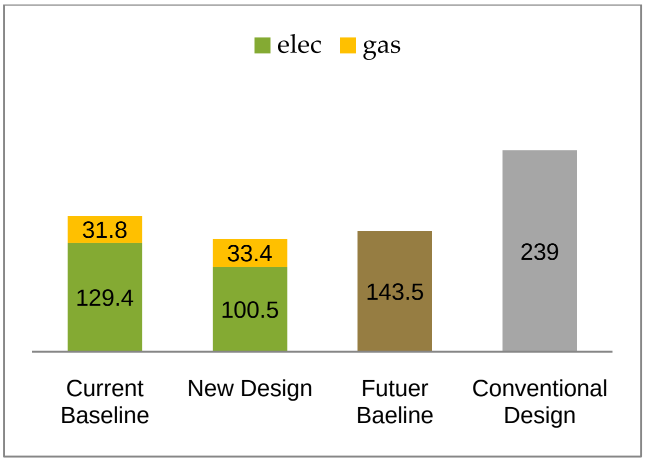


Figure 9-Approximate Trend of energy consumption in mid-rise buildings, ekWh/m²

4.2. GHG Emissions

Based on the GHG emission factors explained in Section 3-2, the Carbon foot print of an average MURB is quantified as 11 $kgCO_2/m^2$ from burnt natural gas and 3 $kgCO_2/m^2$ from electricity consumption, for each year of building operation. Note that the GHG emissions of electricity is the minimum value based on the least emission factor, currently adopted by BC Hydro. However, following the guideline suggested by the Ministry of Energy, Mines and Petroleum Resources (MEMPR), a marginal emission factor of 0.360 kgCO2/kWh should be adopted which will result in much higher GHG emissions per year equal to 43.2 $kgCO_2/m^2$ (even higher than GHG emissions due to gas consumption). This is stated here just to emphasize the high advantage of BC hydroelectric dams and further commitment to conserve this valuable power supply as much as possible. The median factor is 0.055 $kgCO_2/kWh$, provided by NRCan, which will result in total of 6.6 kg $kgCO_2/m^2$ for an average MURB. As previously stated, within this report the value stated by BC Hydro (3 $kgCO_2/m^2$) is considered for GHG emissions from electricity.

Figure 10 shows the share of each end use area in total Carbon foot print from building operation. Conserving energy in the DHW and space heating end use areas (as highly suggested in previous section) are also beneficial in achieving notable reductions in total GHG emissions.

Figure 11, which gives the GHG emission data for each study building, further supports the results of previous section: the higher gas consumption results in higher GHG emissions.

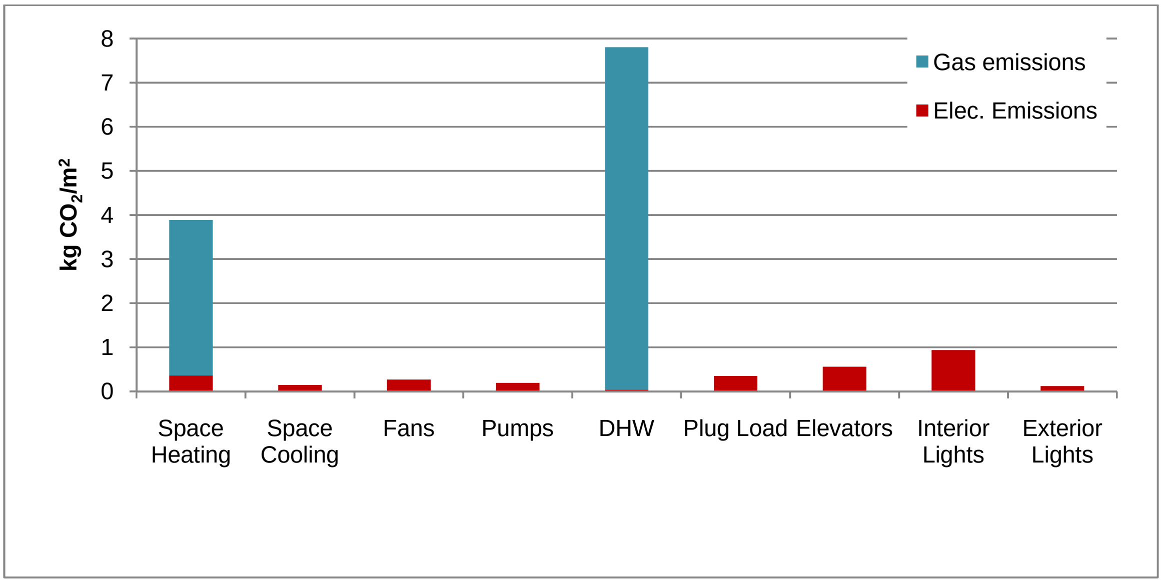


Figure 10-GHG Emissions of Each End Use Area (kgCO2/m²)

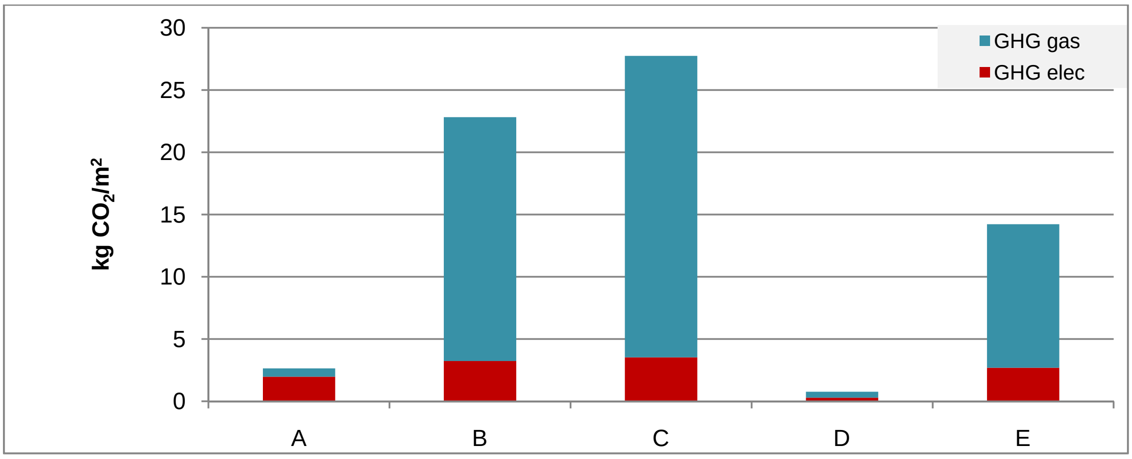


Figure 11-GHG Emissions of Different Buildings (kgCO2/m²)

4.3. Performance of Energy Conservation Measures (ECMs)

Each of the 12 ECMs discussed in Section 3.3 were analysed for total energy saving intensity including electricity and natural gas. Furthermore, a cost/benefit analysis was conducted for each ECM, including simple payback period and net present value. Simple payback period was chosen to be consistent with most of the energy studies and NPV was chosen to take into account the time value of money. Positive NPV values indicate that the ECM is economically viable and is able to pay back for itself during its life expectancy. It should be noted that simple payback period could not be used by itself as an indicator for profitability, since different ECMs have different life expectancies. For example, a measure with an SPP of 8 years and life expectancy of 20 years is acceptable, while another measure with an SPP of 5 years and life expectancy of 4 years is not acceptable, despite the lower SPP for the second measure compared to the first one. To avoid misinterpretation of data, a new term called payback percentage was introduced as the percentage of an ECM's life covered by the savings cash flow, calculated as follows:

$$Payback\ Percentage\ (\%) = \frac{Average\ Simple\ Payback\ Period\ (years)}{Average\ Life\ Expectancy\ of\ Measure} \times 100\%$$

Table 11 shows the analysis results for each ECM in individual buildings as well as average, standard deviation and coefficient of variation. The statistical analysis was carried out due to the high variability of data for a great portion of the ECMs.

2 variables are critical when comparing various ECMs:

- **Energy saving intensity (kWh/m^2):** Which shows the extent of the achievable energy savings; and
- **Payback Percentage (%):** Which gives an estimate on economic feasibility of the ECM.

The ranking of ECMs based on their SPP percentage and Energy Saving Intensity is shown in Figure 11(a) and 11(b) respectively. Ranking of ECMs based on their performance is not straightforward since 2 factors, which are changing simultaneously, should be considered in ranking. To make the comparison possible, ECMs are first ranked based on their performance and then assigned to one of the four categories of A, B, C and D, explained below Table 12. The categories noted above have descending desirability, with category A and D being the most and least desirable ones respectively.

Caution must be taken when dealing with the results since some of the data are less reliable or scattered. An uncertainty analysis is beyond the scope of this project but is recommended.

Table 11-Energy Savings and Cost/Benefit Analysis Results for ECMs.

Building ID	Energy Savings Intensity (kWh/m²)	Electricity Savings (kWh/m²)	Gas Savings (kWh/m²)	Simple Payback Period (years)	Net Present Value ($)	Expected Life (year)	Simple Payback Percentage (%)
Interior LPD Reduction							
A	1.55	1.55	-	4.18	7,602	16	26
C	1.68	1.68	-	13.75	924	16	86
D	3.66	3.66	-	8.68	11,365	16	54
F	0.73	1.14	-0.4	17.48	- 777	16	109
Average	1.90	2.00	-	11.02	4,778	16	69
S.Dev. [49]	1.24	1.13	-	5.82	5,688	-	-
C.O.V[50]	0.65	0.56	-	0.53	1.19	-	-
Interior Lighting Control							
A	0.04	0.04	-	34	- 6,196	8	425
C	0.43	0.43	-	21.23	- 3,163	8	265
D	0.57	0.57	-	33.64	- 8,536	8	421
E	0.96	0.96	-	8.35	-1,928	8	104
F	1.58	1.7	-0.12	10.14	-1,451	8	127
Average	0.72	0.74	-	21.47	-4,255	8	268
S.Dev.	0.58	0.63	-	12.31	3023	-	-
C.O.V.	0.81	0.85	-	0.57	0.71	-	-
Exterior LPD Reduction							
B	0.17	0.17	-	134.4	-15,488	16	840
C	0.44	0.44	-	12.67	497	16	79
D	1.79	1.79	-	4.6	7,737	16	29
Average	0.8	0.8		50.56	- 2,418	16	316
S.Dev.	0.87	0.87	-	72.72	11,883.73	-	-
C.O.V.	1.08	1.08	-	1.44	-4.92	-	-
Exterior Lighting Control							
E	2.36	2.36	-	0.43	100,968	8	5
DHW Low Flow Fixtures							
B	0.8	0.8	-	25.45	-1,306	25	102
E	11.38	-	11.38	1.56	231,313	10	16
Average	6.09	0.8	11.38	13.5	115,003	16.5	82
S.Dev.	7.48	-	-	16.89	164,486	-	-
C.O.V.	1.23	-	-	1.25	1.43	-	-

[49] Standard Deviation
[50] Coefficient of Variation, which equals to the ratio of Sample Standard Deviation to Sample Mean

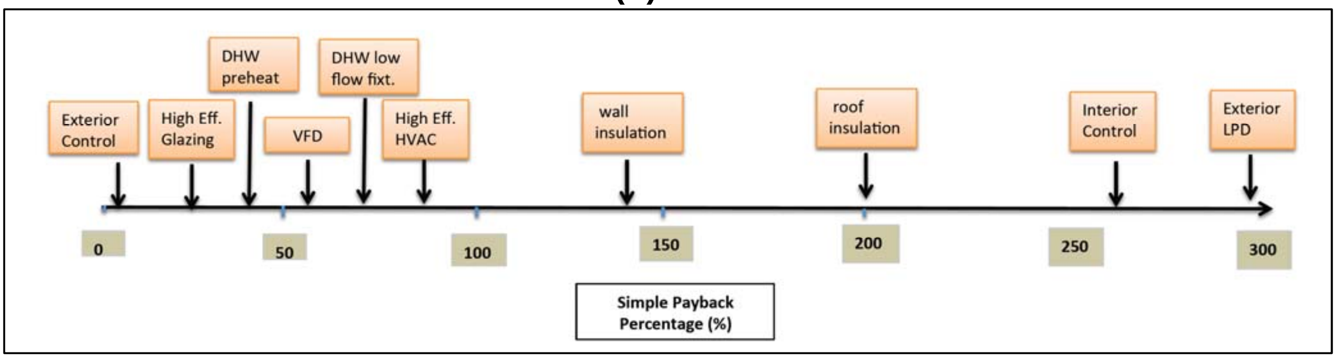
Table 11 (Continued)- Energy Savings and Cost/Benefit Analysis Results for ECMs.

DHW Heating/Pre-heating							
A	14.77	6.1	8.67	1.4	71,518	15	9
F	8.15	-	8.15	14.15	11,194	20	71
Average	11.46	6.1	8.41	7.78	41,356	17.5	44
S.Dev.	4.68	-	0.37	9.02	42,655	-	-
C.O.V.	0.41	-	0.04	1.16	1.03	-	-
High Efficiency HVAC System							
A	24.86	24.86	-	9.22	231,159	20	46
B	45.7	45.7	-	12.22	67,111	15	81
C	3.2	16.63	-13.43	33.39	-102,925	20	167
D	15.1	15.1	-	21.93	-68,187	15	146
E	33.62	35.96	-2.34	3.43	2,171,770	15	23
F	11.23	-	11.23	7.19	58,189	25	29
Average	22.28	27.65	-1.51	14.5	392,852	18.3	79
S.Dev.	15.63	13.05	12.35	11.15	879,449	-	-
C.O.V.	0.70	0.47	-8.18	0.769	2.239	-	-
Variable Frequency Drive (VFD)							
C	18.52	18.52	-	0.75	87,629	10	8
E	0.22	0.22	-	11.01	- 1,654	10	110
Average	9.37	9.37	-	5.88	42,987	10	59
S.Dev.	12.94	12.94	-	7.25	63132	-	-
C.O.V.	1.38	1.38	-	1.23	1.47	-	-
Roof Insulation Increase							
A	0.62	0.62	-	35.19	-11,292	20	176
B	0.22	0.22	-	92.25	-18,824	20	461
D	0.96	0.96	-	32.81	-11,128	20	164
E	0.59	0.59	-	31.73	-47,878	20	159
F	0.94	0.71	0.23	17.69	314	20	88
Average	0.66	0.62	0.05	41.93	-17,751	21	200
S.Dev.	0.30	0.27	-	28.95	18170	-	-
C.O.V.	0.46	0.43	-	0.69	-1.02	-	-
Wall Insulation Increase							
A (by R-4)	1.79	1.79	-	7.5	23,417	20	38
B (by R-10)	0.53	0.53	-	28.6	-3,981	20	143
D (by R-20)	1.68	1.68	-	36.3	-18,089	20	182
E (by R-17.5)	0.84	0.84	-	49.57	-158,296	20	248
F (by R-6)	0.49	0.44	0.05	19.59	314.99	20	98
Average	1.07	1.06	0.01	28.3	-31,327	20	142

Table 11(Continued)- Energy Savings and Cost/Benefit Analysis Results for ECMs.

S.Dev.	0.63	0.64	-	16.01	72,530	-	-
C.O.V.	0.59	0.60	-	0.57	-2.32	-	-
High Efficiency Glazing							
A	10.2	10.2	-	6.56	122,984	30	22
B	15.8	15.8	-	2.45	304,217	30	8
D	7.48	7.48	-	8.31	66,340	30	28
E	8.14	8.14	-	5.73	985,956	30	19
F	0.52	0.46	0.06	16.29	816	20	81
Average	8.43	8.41	0.06	7.86	296,062	28	28
S.Dev.	5.50	5.52	-	5.17	40,1845	-	-
C.O.V.	0.65	0.66	-	0.66	1.36	-	-
Shading							
A	0.45	0.45	-	469	-150,921	30	1,563

(A)



(B)

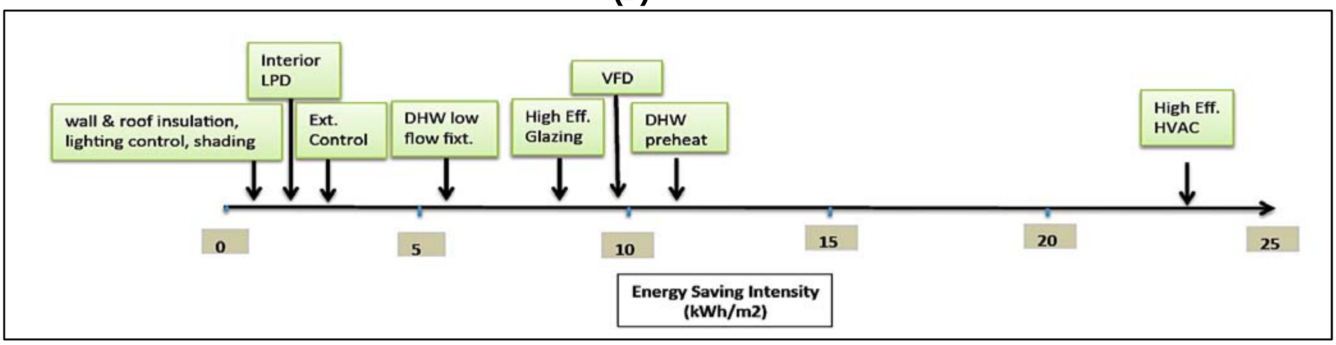


Figure 11-Ranking of ECMs based on their (A) Relative Simple Payback Percentage and (B) Energy Saving Intensity.

Table 12- Effectiveness for energy savings and economic profitability of each ECM

	ECM Type	Effectiveness for Energy Savings	Economic Profitability
Category A[1]	DHW Heating/Preheating	• Rank: #2 out of 12 • High Energy Savings	• Rank: #3 out of 12 • High Profitability
	High Efficiency Glazing	• Rank: #4 out of 12 • Medium-high Energy Savings	• Rank: #2 out of 12 • Medium-high Profitability
	VFD	• Rank: #3 out of 12 • High Energy Savings	• Rank: #4 out of 12 • Medium-High Profitability
	Exterior Lighting Control	• Rank: #6 out of 12 • Medium-high Energy Savings	• Rank: #1 out of 12 • High Profitability
	High efficiency HVAC	• Rank: #1 out of 12 • High Energy Savings	• Rank: #6 out of 12 • Medium-High Profitability
Category B[2]	Interior LPD Reduction	• Rank: #7 out of 12 • Medium-Low Energy Savings	• Rank: #5 out of 12 • Medium-high Profitability
Category C[3]	DHW Low Flow Fixtures	• Rank: #5 out of 12 • Medium-high Energy Savings	• Rank: #7 out of 12 • Medium-low Profitability
Category D[4]	Wall Insulation Increase	• Rank: #8 out of 12 • Medium-low Energy Savings	• Rank: #8 out of 12 • Medium-low Profitability
	Interior Lighting Control	• Rank: #10 out of 12 • Low Energy Savings	• Rank: #10 out of 12 • Low Profitability
	Roof Insulation Increase	• Rank: #11 out of 12 • Low Energy Savings	• Rank: #9 out of 12 • Medium-Low Profitability
	Exterior LPD Reduction	• Rank: #9 out of 12 • Low Energy Savings	• Rank: #11 out of 12 • Low Profitability
	Shading	• Rank: #12 out of 12 • Low Energy Savings	• Rank: #12 out of 12 • Low Profitability

[1] **Category A: ECMs with High Profitability and High contribution to energy savings**
[2] **Category B: ECMs with High Profitability but low contribution to energy savings**
[3] **Category C: ECMs with Low Profitability but High contribution to energy savings**
[4] **Category D: ECMs with Low Profitability and low contribution to energy savings**

According to the results shown in Table 12, DHW heating/preheating, high efficiency glazing, high efficiency HVAC and Variable Frequency Drive installation had the most desirable payback period and energy saving intensity among the studied ECMs. A high uncertainty was associated with the exterior lighting control study since the results of only one energy study was available. A closer look at the ECMs of category A indicates that almost all of the well-performing ECMs run under the space heating and DHW end-use, because of the high share of electricity in final energy consumption.

Interior LPD reduction falls into Category B as it has a reasonable payback period, but a lower energy saving potential. This is why the savings obtained from lighting end-use in current practices, shown in Figure 5, are far below the achieved savings from space heating. In other words, the lower percentage of savings from lighting compared to space heating does not necessarily imply that the lighting area is not appealing to the new constructions, and is solely because of less energy intensiveness of the savings from lighting. Interior lighting controls also fall into Category D and have poor performance. Given that lighting controls are part of the requirements for the next energy code (ASHRAE 90.1 2010), more incentives might be considered.

4.4. Achievable Energy Savings from Building Envelope

Among 12 ECMs discussed in this study, 4 were directly related to the building envelope while the rest achieved savings through improving efficiency. These 4 ECMs include high efficiency glazing, increasing roof insulation, increasing wall insulation, and shading. Only one study was available for shading, which had an extremely high payback period (i.e. 469 years). A high level of uncertainty is deemed to be associated with the results for shading; hence, shading has been excluded from further discussion. The effect of installing high efficiency glazing as well as increasing wall and roof insulation are discussed in the following sections.

4.4.1. High Efficiency Glazing

According to the results from Table 12, installation of high efficiency glazing not only results in significant energy savings, but also has relatively high economic profitability. An excessive glazing ratio i.e. 50% maximum is currently allowed by ASHRAE 90.1 code. Additionally, all-glass residential buildings are highly popular especially in downtown Vancouver. Given that glass has several times less thermal resistance than concrete or wood, a great opportunity exists for achieving energy and cost savings through more energy efficient glazing and/or reducing glazing ratio. Although ASHRAE 90.1 (2010) code has decreased the maximum allowable glazing ratio from 50% to 40%, the opportunity for energy savings will still exist.

4.4.2. Increasing Wall Insulation

Relatively low energy savings and profitability are witnessed for increasing the thermal resistance of walls compared to ASHRAE code. Interestingly, according to Table 11, increasing wall insulation to higher extents has a reverse consequence. In other words, the marginal savings from wall insulation increase are such low that they could not cover the initial investment. One justification for this observation might be that there is no need for extensive insulation as a low temperature difference occurs between two sides of a wall in mild climate of Vancouver. That is why positive NPV values are observed for increasing wall R-value by lower extents (e.g. for Buildings A and F), while increasing R-values to higher extents (e.g. for Buildings B, D and E) result in negative NPV values.

4.4.3. Increasing Roof Insulation

Compared to the walls, increasing roof insulation shows even a worse performance according to 5 building studies. One reason for this low performance is that in high-rise buildings, the roof insulation only covers the ceiling of the top floor, while the savings are divided by the total floor area of the high-rise for EUI calculation. The value of energy saving intensity drops significantly by this procedure. More details on the energy modeling of the studies are required in order to justify these findings in detail.

5. Recommendations to Go Beyond The Code

5.1. General Principles for Low-Carbon Design

Since GHG emission reduction is currently one the most important areas of national and international attention, a number of common principles have emerged for low-carbon design. The principles concerning high-rise MURBs are listed below[51]. Note that these areas are sorted based on their relative cost-effectiveness and priority should be given to the first ones[52].

[51] Light house, intep, BTY Group (2012). Towards Carbon Neutral Buildings in BC, Framework for High-rise Multi-Unit residential Buildings
[52] Parekh, A. (2010). Optimization of Net Zero Energy Houses, BEST 2, *Energy Efficiency- Session EE3-3*

- High performance envelope to minimize heat loss by using a simple architectural layout, massive amounts of insulation and a high degree of airtightness[23];
- High performance mechanical systems for space heating, water heating and ventilation, in order to minimize energy demand;
- Energy-efficient lighting and appliances to reduce the base load as much as possible;
- Natural lighting and passive solar gains by using as much south-facing glazing as possible; and
- Provide the balance of the energy requirements and meet the demand by renewables such as Photo-voltaic panels and solar thermal heaters.

Note that renewables should be employed only when the other 4 measures have been fully utilized in buildings, since renewables are usually expensive sources of energy compared to energy conservation practices.

5.2. Barriers to Energy Efficiency in Residential Buildings

Some of the incentives provided for energy efficiency in building sector market have returned limited results due to several barriers impeding energy efficiency, most of which interacting and strengthening each other[53]. Examples of these barriers are provided in this section.

The most important barrier facing energy efficiency in residential buildings is that people involved in building projects such as professional developers usually show direct interest on the current budget and might be unwilling to evaluate future costs. Since energy efficiency measures, even those with very short payback periods, are associated with relatively high capital costs, they do not seem appealing for construction agents.

Additionally, a split incentive exists in residential market sector where those who make decisions regarding energy, most regularly will not pay the energy bills. There is a rare involvement of building occupants, who pay energy bills, in the building design. This split incentive would potentially hamper buildings' energy performance. Another form of split incentive also happens where someone other than the occupant such as the landlord or

[53] Laustsen, J., (2008). Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, IEA Information Paper, International Energy Agency

strata is responsible for energy bills. A study performed by Finch et al.[54] shows that the average intensity in the buildings of study experienced a significant rise from 172 to 450 kWh/m^2 from studies where the occupants were and were not responsible for their utility bills respectively.

High uncertainty also exists with prices and real estate market fluctuations, which creates a resistance towards energy efficiency measures with higher initial costs. In addition, the owners are not quite certain if the costs would be covered when reselling the building.

Other barriers include comparatively low energy prices in BC, lack of energy efficiency knowledge among occupants, and users' lifestyle choices.

5.3. Potential Areas of Further Energy Savings

As discussed in Section 5.1, energy savings from building envelope is a very cost-effective means of energy conservation. Figure 12 compares some aspects of a representative ASHRAE 90.1 (2004) with 2020 carbon neutral high-rise MURBs.

[54] Finch, G., Burnett, E., & Knowles, W., (n.d.) Energy Consumption in Mid and High Rise Residential Buildings in British Columbia, *BEST2-Energy Efficiency –Session EE3-1*

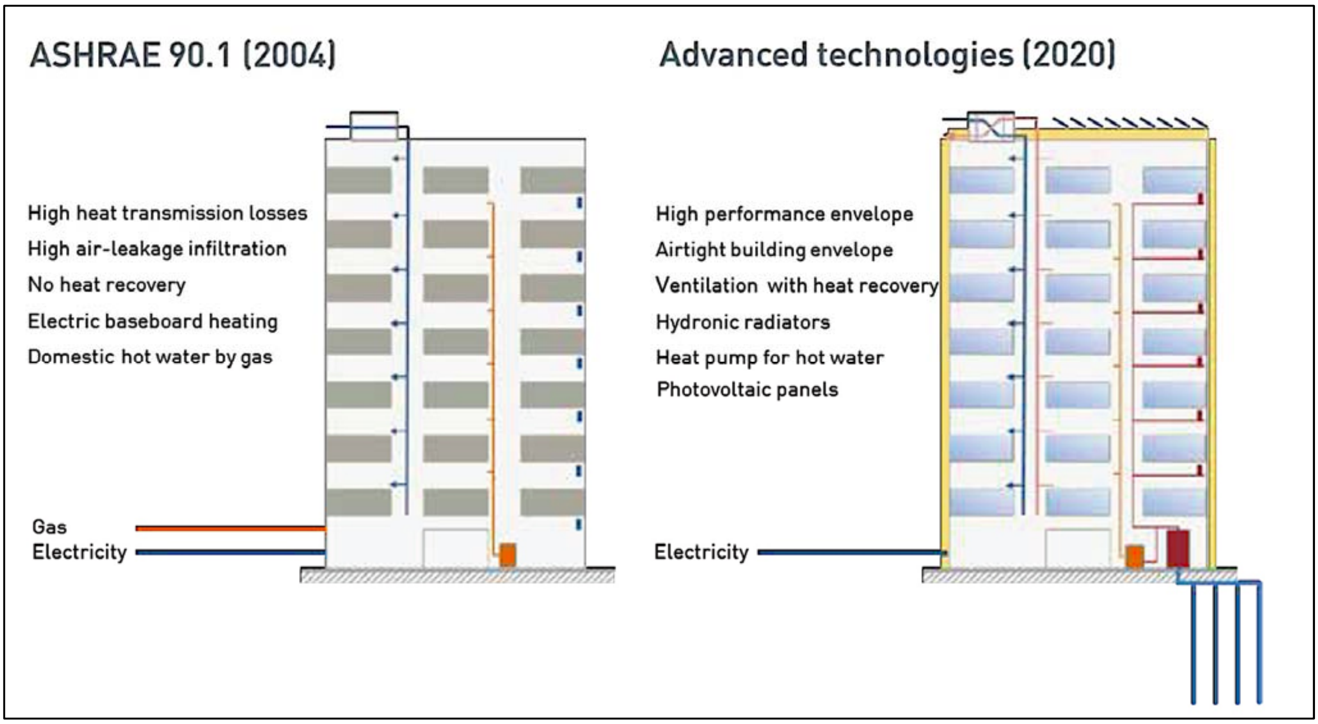


Figure 12. A comparison between a current and 2020 high-rise MURB, Figure adapted from Light house, intep, BTY Group (2012). Towards Carbon Neutral Buildings n BC, Framework for High-rise Multi-Unit residential Buildings

Some examples of innovative efficient measures are discussed in the following sections. Performing cost/benefit and feasibility analysis on these measures is beyond the scope of this study, as it requires involvement in design aspects for the specific buildings,

5.3.1. Move from All-Air Systems to Hydronic Panels

Space heating can be provided by large hydronic panels installed on floor or ceiling levels instead of fan coil units. Substituting all air systems with hydronic slabs will also improve the overall efficiency due to higher area of heat transfer and lower temperature of flowing fluid.

5.3.2. Increase Glazing Efficiency/Reduce Glazing Ratio

Balancing between level of available daylight/view and excessive heat loss/gain through windows is considered the main issue of newly designed MURBs in Vancouver. Relying only on the codes for prescribed R-Values is not sufficient and further limits to improve the overall performance of glazed façade are strongly recommended. Other methods of allowing daylight without excessive heat losses regarding the building form and orientation should be explored for each specific building.

5.3.3. Provide Shading and Shutters for Windows

Well-designed exterior shades will reduce cooling loads during summer without limiting the solar gain during winter. Another solution for heat losses from windows is utilizing window shutters which are effective in blocking heat transfer at night and allowing sunlight during the day. Exterior shutters are preferable regarding the moisture problems of interior shutters/blinds.

5.3.4. Switch to more Efficient Elevators

None of the discussed energy studies involved upgrading elevators to more efficient models. Since elevators' energy consumption involves a notable portion of the total energy, further investigation of the saving possibilities is deemed to be beneficial. As an example, Schindler Germany claims that its 7000 elevator series[55] have taken advantage of state-of-the-art technologies for a reliable and energy efficient experience. These elevators, which have energy efficiency rating A, have been used in a number of remarkable LEED Gold and Platinum buildings worldwide such as International Commerce Centre Hong Kong, World Trade Centre in Beijing (the tallest building in China), Heron tower in London, Hearst Tower in New York (the first LEED Gold building in New York), and Torre Titanium (the first building in Chile certified by U.S. Green Building Council).

5.3.5. Switch from Conventional Boilers to District Energy Systems

Given that large environmental impacts are associated with gas consumption, shifting from gas burning boilers to other efficient equipment seems necessary. The feasible options are listed as:

- District Energy Systems (currently available in some regions in Vancouver);
- Replacing the boilers by heat pumps (for hot water); and
- Enforcing installation of condensing boilers instead of conventional boilers.

[55] The Ultimate High-rise Elevator System (2013), Retrieved from (Schindler) http://www.schindler.com/us/internet/en/mobility-solutions/products/elevators/schindler-high-rise-elevator.html

6. CONCLUSION

Heat pumps are rapidly replacing the electric baseboards used conventionally in currently designed and constructed buildings. Heat pumps are deemed to reduce overall energy consumption levels in new buildings. However a comparison between current natural gas/electricity ratio with historical data shows this reduction in overall consumption is associated with an increase in electrical consumption while decreasing the natural gas consumption. Furthermore, replacing conventional systems with heat pumps does not essentially result in notable energy savings. Therefore, increasing the efficiency of mechanical systems must be combined with reducing internal energy loads and improving energy performance of the building enclosure. The later could be mainly achieved by reducing energy wastes from glazing through well-designed shading, optimized glazing ratio, and installation of high-efficiency glazing. Furthermore, a high potential for natural gas saving and GHG emissions reduction exists for domestic hot water heating, and notable energy saving intensity and profitability was witnessed for all ECMs working in this area. Additional savings could be achieved by using heat pumps for hot water and moving toward district energy systems. Installing VFD on pumps and fans was another cost-effective measure with a high saving potential due to the relatively high share of fans and pumps of total energy consumption (i.e. 12% in total). None of the energy studies included conservation measures on elevators, while elevators account for about 8% of the total consumption. Further investigation of high efficiency elevators is recommended. Given that lighting controls are part of the requirements for the next energy code (ASHRAE 90.1 2010), more incentives are deemed to be necessary for these measure, since long payback periods were observed in this area.

Considering building form and orientation in early design stages will significantly affect building energy consumption with minimal costs compared to passive and active design approaches. This aspect is currently overlooked in many of the new construction projects and requires further consideration.

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